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Effect of Biochar Derived from Different Crop Residues on Soil Water Retention

Foday Saidu Sesay [a] and Alie Kamara [a,b*]

[a] Soil Science Department, School of Agriculture, Njala Campus, Njala University, Sierra Leone.
[b] Njala University Quality Control Laboratory, Njala Campus, Njala University, Sierra Leone.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The water retention capacity of Sierra Leone soils is low due to low organic matter content and the dominance of highly weathered low activity clay minerals such as kaolinite and iron and aluminum sequioxides. It is therefore essential to seek efforts to improve water retention capacity of soils in order to improve crop growth and yield. This research was carried out to study the water retention properties of biochar derived from different crop residues and their influence on soil water retention. The study was conducted at the Njala University Quality Control Laboratory, Njala Campus in Southern Siera Leone (Latitude 8°N and Longitude 12°W). Six biochar types from six crop residues (rice straw, rice husk, groundnut, maize stover, pigeon pea and cowpea) were studied. For each biochar, 10g was saturated with water by capillary action and suspended to allow drainage of excess water. The amount of water retained by biochar was determined by drying in oven to constant weight. The water retention capacity of each soil-biochar mixture was determined in a similar manner; where, 10g of a fine sandy loam soil was mixed with biochar at different rates (0.2,

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**Corresponding author: E-mail: aliekamara@njala.edu.sl;*

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0.4, 0.6, and 0.8g/10g soil). The study revealed that the water retention capacities of the different biochar types depended on the biomass type. However, the retention capacity of different biochar types was not clearly reflected on their soil-biochar mixtures. For example, biochar derived from Maize stover which had lower water retention capacity than Rice straw biochar showed higher soil water retention than Rice Straw biochar in the biochar-soil mixture. This showed that water retention capacity of pure biochar is not a direct measure of its capacity to improve soil water retention. However, this requires further investigations. The study also revealed that water retention capacity of biochar-soil mixtures increased with increasing biochar application levels. However, signgificant effects were observed with higher application rates. Fractionation of biochar did not produce any regular pattern in water retention.

Keywords: Water retention capacity; crop residue biochar; Sierra Leone soils.

1. INTRODUCTION

Plant growth and yield is directly related to water and nutrient availability. When a soil has low capacity to retain water and make it available for crop use, crops suffer from water stress and results in poor crop growth and yield. On the other hand, a soil with high water holding capacity decreases the need for irrigation and improves crop yields (Brady & Weil, 2017, FAO, 2017). Even in high rainfall areas like Sierra Leone, the effect of low water retention capacity on crop growth and yield can be important during short duration dry spells in the rainy season and may be particularly significant at the start (mid-April/May) and end (October/mid-November) of the rainy season. During the dry season, low water retention becomes a serious constraint to crop production.

Generally, Sierra Leone soils are dominated by low activity clays (mostly kaolinite and sesquioxides) with low water retention properties (Dijkerman, 1969; Bationo *et al*., 2006). Furthermore, soil organic matter, which enhances water retention in soils is low in Sierra Leone soils. Additionally, continuous cropping has led to the depletion of the soil organic matter resulting in reduction of the ability of soil to retain and make water available for plant growth. This problem is particularly serious on sandy or coarse-textured soils (such as those found in the Newton Land System and Bolilands of Sierra Leone), which have low water retention capacities. Farmers working on such soils are faced with the challenge of improving water availability to crops. Identification and development of simple, low-cost methods for improving soil water retention and availability suited to the farmers' environment require urgent attention. Thus, any effort to improve water retention capacity of soils could be of relevance to improving crop growth and yield.

Some of the approaches that have been used for improving soil water retention include mulching (Li et al., 2019), cover cropping (Basche & DeLonge, 2017), manure input (Bakayoko et. al, 2013, FAO, 2017) and the application of soil conditioners such as hydrogels (Krasnopeeva, E. L., et al., 2022). However, these techniques have short-lived residual effect. A longer-lasting solution to the problem of water deficit is the application of biochar. Application of biochar improves water retention and availability (Liu et al., 2016) since it has similar characteristics to that of organic matter. Consequently, the application of biochar to soil is an important approach to improving water retention in soils and ensuring improved soil water and crop relationship and better crop yields. Therefore, the objectives of this study were to determine (i) the water retention properties of biochar derived from different crop residues and (ii) their effect on soil water retention capacity.

2. METHODS

2.1 Description of the Study Area

The study was conducted in the Njala University Quality Control Laboratory (NUQCL) located in Moyamba District, Southern Sierra Leone. Njala is about 205km from Freetown, the capital city of Sierra Leone, and is located at an elevation of 128m above sea level (altitude), on Latitude 8ºN and Longitude 12ºW. The soil used to conduct the experiment was sampled in the Njala area and belongs to the Mokonde series, a fine sandy loam which has been classified as Plinthic Haplustox. The climate is characterized by two distinct seasons, rainy and dry. The rainy season lasts from May to November and the dry season from December to April. The average annual rainfall is about 2500 mm most of which falls in July and August.

2.2 Soil Sampling

A composite soil sample was collected to a depth of 20 cm from the Mokonde soil series. The soil sample was air dried and sieved to pass through a 2 mm sieve and stored.

2.3 Crop Residue Collection and Production of Biochar

Six different types of crop residues (rice straw, rice husk, maize stover, groundnut shells, cowpea stalks, and pigeon pea stalks) were collected from farms around Njala University campus. Each crop residue was thoroughly sun-dried and converted to biochar using a top-lit up-draft bioenergy stove called Elsa. At the end of the pyrolysis, the charred material (biochar) was emptied into a container and quenched with water. It was then allowed to air dry for three days and then sun-dried for a day. The dried samples were crushed and sieved to pass through the 2 mm sieve.

2.4 Water Retention Studies

2.4.1 Biochar water retention

A tin of about 25 cm^3 was cut opene at both ends and a wire mesh sealed to one end to allow free drainage of water and weighed. Then, 10g of each type of biochar was weighed and placed in the pre-weighed tin. The tin containing the biochar was placed in water to a depth of about 2 cm for six hours to allow capillary rise and saturation. The tin and its saturated biochar were removed from the water. The top of the tin was covered with parafilm to prevent evaporation of water. Then, the tin was suspended on a retort clamp stand to allow gravitational water to drain for six hours. The tin containing the moist biochar was weighed and dried in an oven at 105 ^{0}C for 48 hours. A blank (empty) tin was included in the procedure to account for the moisture retained by the tin. The percentage moisture retention was calculated using the equation below:

$$WRC\ (\%) = [(W_2 - (W_3 + W_4)/(W_2 - W_1)] \times 100$$

Where

WRC (%) is the percentage water retention capacity
W_1 is the weight of the empty tin
W_2 is weight of tin plus moist biochar
W_3 is the weight of the tin plus the oven dry biochar
W_4 is the moisture retained by the tin

2.4.2 Biochar water retention

Biochar was added to soil at rates of 0, 2, 4, 6, and 8g/100g soil and homogenized. Then 10g of each biochar-soil mixture was placed in the pre-weiged tins and tretead as described for the biochar above.

2.5 Data Analysis

All data obtained were subjected to analysis of variance (ANOVA) and mean comparison using GenStat.

3. RESULTS AND DISCUSSION

3.1 Water Retention Properties of Different Biochar Types

The water retention capacities of different biochar types are shown in Fig. 1. Biochars vary in their water retention properties. Generally, the different biochar types absorb water in quantities ranging from three to five times their own weight. Pigeon pea biochar had the highest water retention capacity and absorbs water about five times its weight. Cowpea, on the other hand, had the lowest water retention capacity absorbing about three times its own weight of water. The order of increment in water retention capacities of biochar derived from crop residues is cowpea<rice husk<groundnut<maize stover<rice straw<pigeon pea. The differences can be explained in terms of the differences in porosity of the different biochar types.

3.2 Effect of Different Biochar Types on Soil Water Retention Capacity

The influence of different biochar types on soil water retention is shown in Table 1. Generally, the water retention of the soils treated with biochar exceeded the control (soil without biochar) and the water retention capacity of the soil increased with an increase in the level of biochar application.

The effect of biochar application on soil water retention can be described by both linear and polynomial models (Figs. 2a and 2b). The predicted water retention capacity of the soil without biochar as indicated by the intercept is much higher than the measured soil water retention for the linear model than for the polynomial model. The polynomial model was more accurate in predicting the zero condition (i.e. soil without biochar) than the linear model. This is evident in the r^2 values for the two models (Table 1) being higher for the polynomial than for the linear. Thus, the polynomial model was a better fit for the results. From the polynomial model, the initial increase in soil moisture after addition of 20 g biochar/kg soil was much higher than subsequent increases in soil moisture with further additions of biochar. This showed a diminishing effect indicating a trend towards optimum soil water retention with biochar additions (Fig. 2b).

Using the polynomial model, the predicted maximum water retention capacity of each biochar type is shown on Table 2. All biochar samples have different optimum application rates to attain optimum water retention. Cowpea biochar had the lowest optimum application rate (75.36g/kg soil) to attain an optimum water retention of (818.89g/kg soil) while Rice straw biochar had the highest optimum application rate

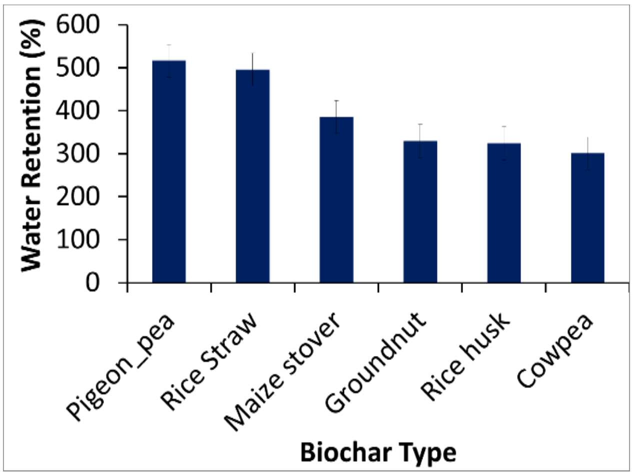
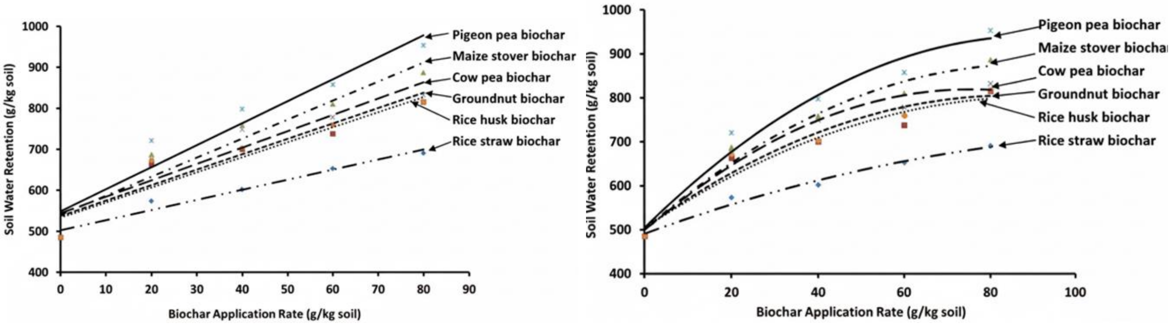


Fig. 1. Water retention capacity of biochar derived from different crop residues



2a 2b

Fig. 2. Linear (2a) and polynomial (2b) relationships between soil water retention potential and biochar application rate for biochar samples derived from different crop residues

Table 1. Comparison between the linear and polynomial models

Biochar Type	Linear model	R^2	Polynomial model	R^2
Rice Straw	$y = 3.675x + 533.2$	0.8959	$y = -0.0139x^2 + 3.5743x + 491.26$	0.9839
Rice Husk	$y = 3.76x + 537$	0.8904	$y = -0.0359x^2 + 6.5464x + 504.49$	0.9437
Maize Stover	$y = 2.46x + 502.4$	0.9665	$y = -0.048x^2 + 8.4779x + 501.57$	0.9733
Cowpea	$y = 3.985x + 544.2$	0.875	$y = -0.0563x^2 + 8.485x + 499.2$	0.9726
Pigeon Pea	$y = 4.635x + 540$	0.9181	$y = -0.0534x^2 + 9.6364x + 505.69$	0.9691
Groundnut	$y = 5.365x + 548.4$	0.9181	$y = -0.0418x2 + 7.1029x + 503.57$	0.952

Table 2. Optimum biochar application rates and the corresponding optimum soil water retention potentials calculated from the polynomial model for biochar samples derived from different crop residues

Biochar Type	Calculated optimum biochar application rate (g/kg soil)	Calculated optimum soil water retention potential (g/kg soil)	Increase in soil moisture retention at optimum biochar application rate relative to control soil (%)
Rice Straw	128.57	721.04	48.67
Rice Husk	91.18	802.93	65.56
Maize Stover	88.31	875.92	80.60
Cowpea	75.36	818.89	68.84
Pigeon Pea	90.23	940.43	93.90
Groundnut	84.96	805.31	66.04

to attain the lowest optimum water retention. Pigeon pea biochar showed the highest optimum soil water retention at an application rate of 90.23g/kg soil. Generally, the results showed that addition of biochar to soils at optimum rates can increase soil water retention greatly, varying from 48.67% for rice straw biochar to 93.9% for pigeon pea biochar (Table 2).

It was expected that the trend in water retention capacity of pure biochar (i.e. cowpea<rice husk<groundnut<maize stover<rice straw<pigeon pea) could be reflected in the water retention of the respective soil-biochar mixtures. However, the effect of applying biochar derived from crop residues on soil water retention capacity was in the order: rice straw < rice husk < groundnut < cowpea < maize stover < pigeon pea. For example, it was expected that the soil-cowpea biochar mixture would have the lowest water retention because its pure biochar had the lowest water retention potential (see Fig. 2a&2b). Instead, rice straw biochar had the lowest water retention when applied to soil. Only pigeon pea biochar maintained its position in the trend i.e. it had the highest water retention for pure biochar and for soil-biochar mixture. Thus, the water retention potential of different pure biochar materials cannot be used as a basis to compare their effects on soil water retention. This observation is in agreement with the work of Kinney et al. (2012) who reported that the hydrologic behaviour of pure biochars does not necessarily predict their behaviour in soil-biochar mixtures. Biochar hydrological properties depend on its hydrophobicity and porosity (Rashwin et al., 2025; Gray et al., 2014; Kinney et al., 2012). Hydrophobicity is affected by production temperature while porosity is affected by biochar type (Gray et al., 2014). A thorough understanding of the interplay between hydrophobicity and porosity of biochars will help in predicting the hydraulic behaviour of soil-biochar mixtures.

4. CONCLUSION

The Biochar obtained from six crop residues was screened for their water retention properties in both pure biochar and in biochar soil mixture. Biochar derived from pigeon pea showed the highest water retention capacity and exceeded all other biochar types even in soil-biochar mixture. For the other biochar types, the retention capacity was not clearly reflected on their soil-biochar mixtures. One could be high in the pure biochar but will fall below another in the soil-biochar mixture. Overall, the water retention of the soils treated with biochar exceeded the control (soil without biochar) and the water retention capacity of the soil increased generally with an increase in the level of biochar application. Hence, the application of biochar derived from crop residues is a promising approach to sustainable water management and could be more efficient if the appropriate type (like Pigeon pea) is selected.

For practical implementation, especially at farm level, there is need for targeted recycling of crop residues via biochar production to enhance soil moisture retention especially in sandy soils. Furher studies at farm level could develop scalable and cost-effective approaches for farmers to recycle their crop residues through biochar production. On-farm trials should be conducted to quantify its impact on irrigation water use efficiency and crop yields especially during the dry season in Sierra Leone. Also, integrating biochar produced from crop residues, such as pigeon pea biochar, into conservation agriculture programs could offer additional benefit of enhancing soil water storage while utilizing agricultural residues thereby enhancin utilization efficiency of farm waste and creating a more sustainable and climate-resilient agricultural system.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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